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Book of Abstracts
November 2-5, 1998

Kellie Ann Beall, Editor

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United States Department of Commerce
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U.S. Department of Commerce
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Modeling of Thermocouple Behavior in Room Fires

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As part of a NIST effort to characterize the uncertainties of temperature measurements in fire environments, idealized models of bare-bead, single-shielded aspirated, and double-shielded aspirated thermocouples were developed and used to study the effects of varying gas and average effective surroundings temperatures on percent error in measured temperature of each type of thermocouple. Steady-state, non-linear, algebraic energy balance equations combined with appropriate convective heat transfer correlations were solved. Probe and bead sizes closely matched those used in recent NIST experiments [1]. Only one previous study has addressed aspirated thermocouples in fires [2].

Figure 1 depicts the predicted percent error in measured temperature for a 1-mm diameter, bare, spherical thermocouple, as a function of average effective surroundings temperature (T_∞), for a few gas temperatures (T_g) between 300 K and 1400 K. Percent error is defined as the difference between the thermocouple temperature and the true gas temperature expressed as a percentage of the latter, where all temperatures are absolute. The region where T_g is higher than T_∞ is termed the "upper layer," recognizing that the region includes but is not limited to the conditions generally found in the upper layer of a room fire. Similarly, the region where T_g is lower than T_∞ is termed the "lower layer." The ovals are printed on the figure to indicate that upper layer ($T_g > T_\infty$) conditions generally occur on the left side of the graph and lower layer ($T_g < T_\infty$) conditions generally occur on the right side. Figure 1 shows that a bare bead thermocouple behaves differently in the upper and lower layers of a room fire. In the upper layer, the percent error for a given T_g is relatively insensitive to T_∞, decreasing gradually to zero as T_∞ approaches T_g. In this region, percent error increases with increasing T_g. In contrast, in the lower layer, percent error is a strong function of both T_g and T_∞, increasing more and more rapidly with increasing T_∞ when the latter value is relatively high. In this region, percent error decreases with increasing T_g. The behavior in both regions is controlled by the fourth-order dependence of the radiation heat transfer rate on T_∞. The most extreme errors occur in the lower layer when T_g is at its lowest assumed value (300 K) and T_∞ is at its highest (1400 K), which would most likely be encountered during a fully-involved room fire.

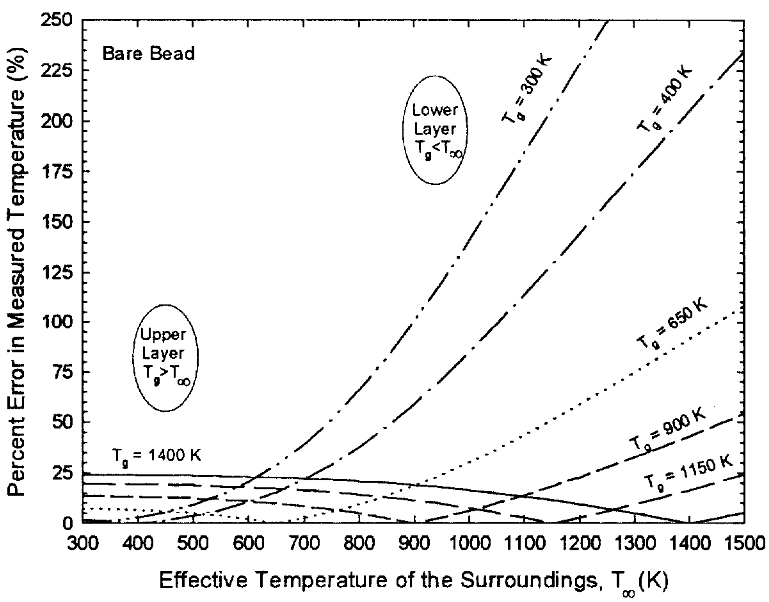

Fig. 1. Effect of surroundings temperature on percent error for a bare-bead thermocouple with diameter of 1 mm, emissivity of 0.8, and external flow velocity of 0.5 m/s.

Figure 2 depicts model results for percent error in measured temperature of a single-shielded aspirated thermocouple. The single-shielded probe behaves similarly to the bare bead, except errors in the upper and lower layers are reduced for a given T_g and T_∞, and the region of rapidly increasing error in the lower layer is shifted to higher T_∞. This shift is expected to decrease the likelihood that the region of high error will be experienced by the thermocouple in a fire test, based on the assumption that a lower-layer thermocouple is less likely to experience a given T_∞ as T_∞ increases to 1400 K and above. Although not shown here, the present modeling indicates that a double-shielded probe reduces errors further than a single-shielded one in both the upper and lower layers of a room fire.

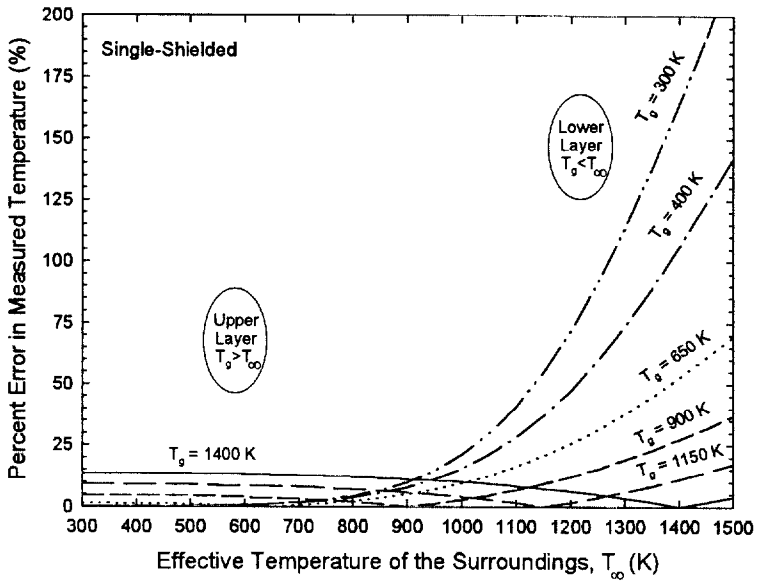

Fig. 2. Effect of surroundings temperature on percent error for an aspirated thermocouple with bead diameter of 1 mm, shield diameter of 8.6 mm, bead and shield emissivities of 0.8, external flow velocity of 0.5 m/s, and aspiration velocity of 5 m/s.

The use of an aspirated thermocouple reduces measurement error, but does not eliminate it. Figure 3 depicts model results for the temperature indicated by a single-shielded thermocouple (T_b) as a function of aspiration velocity (u) when T_g and T_∞ are 300 K and 1200 K, respectively. The predicted error is 60 % when using the ASTM-recommended 5-m/s aspiration velocity [3]. Hence, aspirated-thermocouple users are cautioned that, under certain conditions, the ASTM-recommended velocity is too slow to adequately reduce thermocouple error.

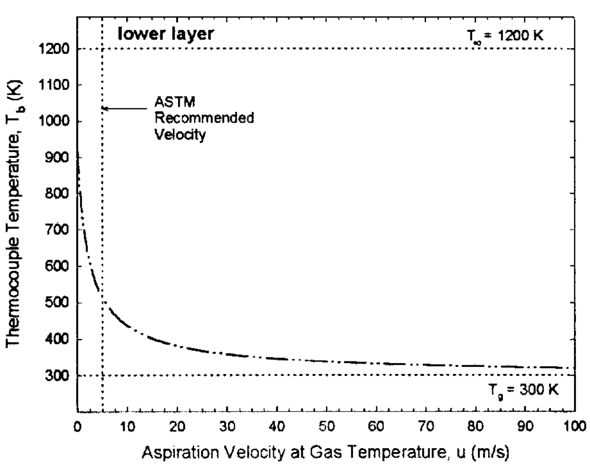

Fig. 3 Predicted aspirated-thermocouple response to variation in aspiration velocity in a lower layer. An ASTM-recommended 5 m/s exhibits 60% error.

In summary, thermocouples respond differently to changes in effective surroundings temperature in a hot upper layer than in a relatively cooler lower layer of a room fire. The most extreme errors occur in a lower layer when T_g is low and T_∞ is high. Finally, an ASTM-recommended aspiration velocity of 5 m/s may be too slow under certain conditions.

1. Pitts, W.M., Braun, E., Peacock, R.D., Mitler, H.E., Johnsson, E.L., Reneke, P.A., and Blevins, L.G., "Thermocouple Measurement in a Fire Environment." NIST Internal Report (to appear), 1998.

2. Newman, J.S., and Croce, P.A., *J. Fire Flammability* 10:327-336 (1979).

3. ASTM Standard E 603-95a, *1996 Annual Book of ASTM Standards*. ASTM Publication Code 01-040796-10, West Conshohocken, PA, 1995, p. 589.